A pluridisciplinary methodology for intregrated management of coastal aquifer - Geological, hydrogeological and economic studies of the Roussillon aquifer (Pyrénées-Orientales, France)

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A PLURIDISCIPLINARY METHODOLOGY FOR INTEGRATED MANAGEMENT OF A COASTAL AQUIFER
Geological, hydrogeological and economic studies of the Roussillon aquifer (Pyrénées-Orientales, France)

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GEOLOGY
HYDROGEOLOGY
EXPERIMENTAL ECONOMY
WATER MANAGEMENT STRATEGIES
SEAWATER INTRUSION
COASTAL AQUIFER
ROUSSILLON BASIN
MEDITERRANEAN SEA
GROUNDWATER

ABSTRACT. – In order to study Mediterranean coastal water management, a pluridisciplinary approach is developed. Reservoir geology and some of its tools, used in oil prospecting, are applied to build a detailed sedimentary model. The analysis of depositional environments and sedimentary process allows the correlation of pre-existing data (outcrop, borehole, and seismic profile) using Genetic stratigraphy (onshore domain) and seismic stratigraphy (offshore domain). The interpretation results in a better knowledge of the sedimentary geometries following correlations between onshore and offshore domains. It is thus possible to differentiate the coastal groundwater aquifers precisely and to establish their relative connections. At the same time, hydrogeological investigations such as hydrochemistry and geophysical prospecting allow us to elaborate the hydrogeological conceptual model of the case studies. Variable-density flow and solute transport simulations constitute the hydrogeological work. Experimental economy constitutes the third part of this integrated methodology. It assesses the effectiveness of institutional arrangements to cope with aquifer overexploitation. Feed-back from these three fields of research will also authenticate our methodology. This approach applied on Roussillon basin (south-west of the French Mediterranean coastline) could be exported to many other coastal areas.

INTRODUCTION

From time immemorial, littoral zones are considered as important places for economic development. Today, 60% of the world population lives close to the sea (less than 60 kilometres). Economic development like population growth, tourism development and cultivated land expansion require more and more quantity of water in these coastal areas. Low quality surface water could be directly used by industry and farmer while drinking water must be treated and/or should be supplemented by groundwater. However, exploitation of deep natural water resources is problematic in coastal areas because of the geological, hydrogeological and economic context.

Most of the time, geology of coastal areas is complex because of the influence of eustasy, like a pronounced boundary condition. Aquifers, as a function of geology, are multilayered and vulnerable to seawater intrusion; conflicts of interest and overexploitation of aquifers can lead to economic losses. Thus, any conscientious coastal aquifer management strategy cannot disregard one of these aspects.

Consequently, the aim of our integrated study is to propose a new methodology to elaborate optimised groundwater management taking care of the geological, hydrogeological and economic context of coastal area. Then, the innovative side of our work lies in evaluating the hydrogeological and economic impacts of selected management strategies given a particular context (geological, hydrogeological and economic). In consequence, a pluridisciplinary approach is unavoidable. In this way, economical study needs quantitative hydrogeology to build realistic experimentation; and hydrogeological modelling needs scenario proposition stemming from socio-economic context. In the same way, geology assists hydrogeological studies by providing details of aquifer structure and architecture; and hydraulic head evolution, which could prove connections between different sedimentary units.

Since the main aim of the study is to develop a methodology which could be applied to other sites as well, the selected study area must be representative of the Mediterranean coastal areas. The selected study area for carrying out this interdisciplinary approach is the Roussillon basin, located along the southernmost part of the French Mediterranean coast, near the Spanish border. This 700 square kilometres sedimentary basin is bordered by the foothills of the Pyrenean Mountains in the South, the Corbières karst region in the North and the Mediterranean Sea in the East (Fig. 1). Influenced by "the Golfe du Lion" rift-

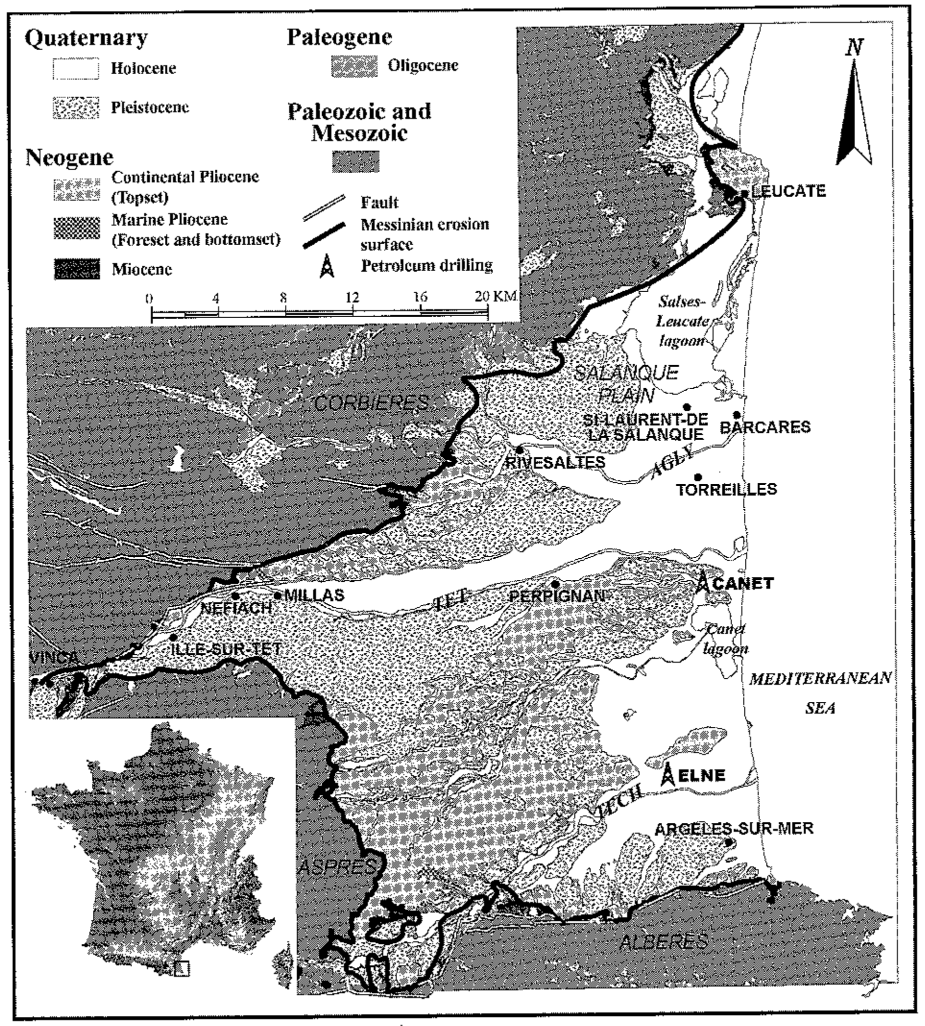

Fig. 1 – Geological view of the Roussillon basin

ing, by the Messinian salinity crisis and by Quaternary glacio-eustatic cycles, geology of the case study has undergone and recorded majority of high recent geological events. Also, the hydrogeological problem is common for this coastal area: water of the Roussillon basin is intensively used as water supply, for coastal tourism and its related activities and in agriculture for irrigating orchards and vegetable crops. Roughly speaking, the water needs of the Roussillon plain are satisfied by a well developed irrigation channel network (surface water) and a highly productive groundwater system. Decline of water tables which has been observed during the last 20 to 30 years is expected to continue as the population keeps growing and the farming sector progressively leaves ancient surface canal irrigation systems and relies more on groundwater use. As overexploitation could lead to local and then general seawater intrusion, policy makers are increasingly looking for means to reduce water abstraction and increase alternative water supply.

As a consequence of climate changes and the demographic growth, this situation could be worst in the future. The high population growth rate observed during the last 20 years, seems to keep accelerating (population has grown from 392 000 in year 1999 to 413 000 in 2005) and with an anticipated higher water demand for household consumption. In addition, climatic variations such as uncertainty about rain falls (principal recharge factor of the superficial layer) in addition to the existing problems such as high number of dry years, increases the dependence and demand of groundwater resources.

The paper develops the methodology related to its three major components (geology, hydrogeology and experimental economy) without further detailed explanation about the scenario conception issues. The paper is organised as follows: the first part deals with geological results obtained from the methodology applied on Roussillon basin. Coastal aquifer problematic and hydrogeological background are tackled in the second part. Then, experimental socio-economical aspects and associated tests are presented.

GEOLOGICAL APPROACH OF THE ROUSSILLON BASIN

The primary geological work involves the determination and location of the sedimentary units, and particularly those that could be potential aquifers. Below, we will see how these sedimentary units are spatially characterised by both their internal and external structure.

Trace the history of the Roussillon basin

Mediterranean coastal areas have many common geological characteristics because of the Messinian salinity crisis existence (Hsü *et al.* 1973). Defined by the drying up of the Mediterranean Sea in late Miocene this main event is linked to the closing of the Strait of Gibraltar (stopping connections between the Mediterranean Sea and the Atlantic Ocean (Benson *et al.* 1991)). Immediate effect was digging out of deep canyons by fluvial erosion (Clauzon, 1982, Guennoc *et al.* 2000). After Pliocene sea return, the huge accommodation explains on one hand the atypical Pliocene sedimentation and, on the other hand the homogeneity of Pliocene sediments structure all around the Mediterranean Sea.

The first aim of our geological study is to test the use of BRGM's (French Geological Survey) public underground database (French regulation requires to declare all wells deeper than 10 m). The aim of the exercise was to see if it was possible to build a high-resolution sedimentary model based on this existing database. More than one thousand wells having underground geological information have been taken into account. The first attempt of lithostratigraphic model (Duvail *et al.* 2001) arises from Clauzon's sedimentation model (Clauzon 1990) and new field works (Le Strat *et al.* 2001). This attempt gives a rough sketch of the basin lithostratigraphical structures. Geological basin analysis was further refined using geophysical borehole logging (gamma-ray and resistivity). First interpretative cross-sections arise, straight away correlated with offshore seismic petroleum profiles (Duvail *et al.* 2005).

Then, the "high-resolution" correlations were applied to the whole sedimentary basin integrating the assessment of 638 wells. This article summarises geological analysis methodology and presents the sedimentary model (Fig. 2): space distribution sketch of the Pliocene and Quaternary sedimentary units for the Roussillon basin.

Methodology

Geological methodology uses 6 main steps: they are (1) field observations leading to (2) geological map of the Roussillon basin and helping in (3) onshore borehole analysis. This analysis takes similar action with offshore seismic profile assessment. Correlations between offshore (4) and onshore domains (5) taking care of the correctness of all the selected data and without neglect (6) stacking evolutions patterns and chronostratigraphic framework. Finally, 2D cross-sections shows (7) spatial distribution of sedimentary prisms (Fig. 2) while isohypse maps (3D) outline the depth and thickness of sedimentary units.

Outcrop observation analysis: Lithology, sedimentary structure and biological contents make up sedimentary facies description. This step is based on many pre-existing field works and new observations/analysis, in the framework of a BRGM's project: "Geological map of France". Depositional environments are given according to the principles of sedimentary facies models (Walker 1984) and facies associations.

Geological map: All geological formations of the Roussillon basin are summarised in a lithostratigraphic synthesis (Duvail *et al.* 2001) based on the sedimentological model selected (Clauzon 1990) after the outcrop observations. This document constitutes the foundation stone of geological interpretations presented below.

Analysis of onshore well logging of the Roussillon basin: Boreholes having well logging are used as benchmark: the logged wells comprise mainly of public drinking water supply wells and two deep drilling wells (Elne 1 & Canet 1) from Petroleum Company. In total, 94 well logs are interpreted and 10 "high-resolution" cross sections were set up. With the aim of keeping maximum consistency, distance between two adjacent well logs must always be lower than 4 km in the case of Pliocene correlations or 2 km for Quaternary formations.

High-resolution geological study is based on genetic stratigraphy concepts (Guillocheau 1991, Homewood *et al.* 1992, Cross *et al.* 1993) which identify little stratigraphic units with isochronal boundaries. Depositional environments are given by usual methodology for well logging interpretation (Serra 1985, 1989, Walker 1984), helped by cutting description associated with outcrop observations. Paleoenvironmental evolutions define the stacking pattern. They are inferred from vertical sequences of depositional environments. These evolutions could be landward (transgressive) or seaward (regressive).

Cross sections provided from correlations between well logs allow an extrapolation to borehole without any logging. Consequently, more than 500 coherent lithological descriptions from driller observations are integrated in a GIS: top and base of 41 sedimentary units have been filled in.

Analysis of offshore seismic section: Data come from (i) "Total" petroleum company for continental margin scale and from (ii) University of Perpignan (BDSI) for superficial coastal prism. Geometries (Duvail *et al.* 2005, Labaune 2006) inferred from sequence stratigraphy concepts (Vail *et al.* 1987, Posamentier *et al.* 1988) in which evolution of stacking patterns is determined by both sharp study of offlap-break stacking patterns (Homewood *et al.* 2002) and kind of sedimentary surfaces.

Correlations between onshore and offshore domains: The correlation methodology consisted of examining the stacking

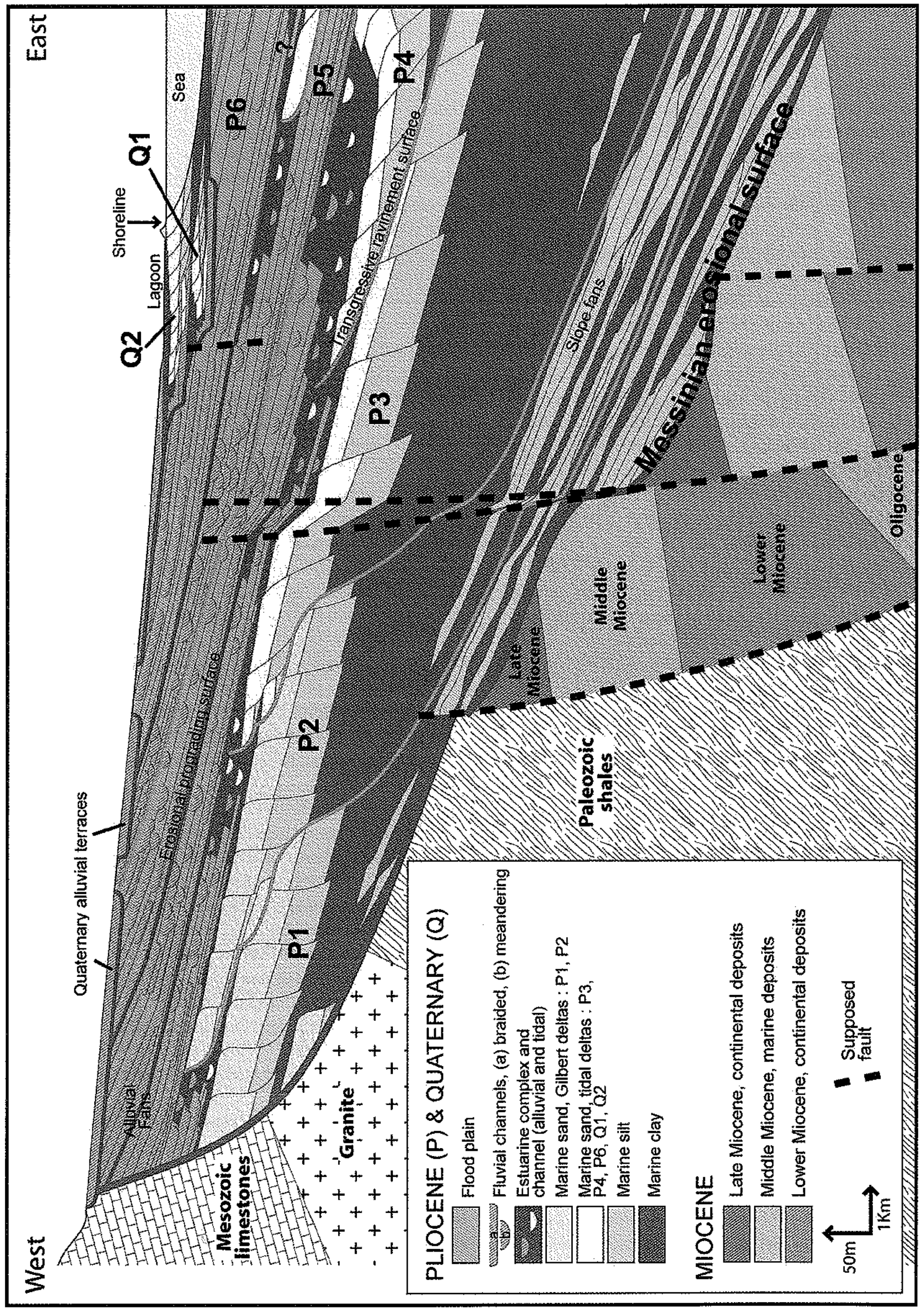

Fig. 2 – Schematic cross-section of the sedimentary fill-in of the Roussillon basin, providing from high-resolution onshore-offshore correlations based on outcrop observations, well logging, lithological borehole descriptions and seismic survey (BDSI and Total).

patterns between the onshore and offshore domains, considering most rigorous stratigraphic framework. This included the stacking patterns of the genetic units identified on the onshore well logs and the stacking patterns of the offlap breaks identified on the seismic profile offshore.

Roussillon basin summary illustration: General theoretical cross-section of the Roussillon basin shows Pliocene and Quaternary prisms with their internal geometry function of the sedimentary facies distribution (Fig. 2).

In the onshore domain, six prisms are identified: marine facies of P1 to P4 are well recognised while P5 and P6 show only continental facies. Quaternary sedimentation expressed by alluvial terraces, exists also with high sea level prisms. Q1 corresponds to the start of an interglacial stage particularly preservation (Salanque plain) during Pleistocene. Holocene Coastal sedimentation is represented by Q2. In onshore domain, 41 units are individualised by prisms geometry and sedimentary facies distribution. In the same way, isohypse maps point out facies distribution.

Multi-scale approach characterises original features of the geological study: outcrop observations and well logging (metric scale), high-resolution seismic surveying (decametric scale) and oil seismic prospecting (kilometric scale) are correlated with the best well-defined coherence. So, this Plio-Quaternary basin analysis underlines geological events of a Mediterranean coastal plain for a scattered scale as regional/margin scale. Moreover, it suggests new methodology for use and validation of geological database characterised by numerous kind of data of different quality.

ROUSSILLON'S GROUNDWATER: A COMPLEX MULTILAYERED COASTAL AQUIFER

Water management and preservation begins by increasing resource knowledge. Recording of water level and water quality time series makes up the first step to understand the functioning of coastal aquifers. Of course, chemical and hydraulic head evolutions must be integrated in a good geological framework. In the case of the Roussillon multilayered aquifer, geological database mentioned above is implemented by screening information: in fact, detailed and exact geological information is available in most cases for water abstraction wells. This information is of the utmost importance to the Roussillon basin considering recently as a multilayered aquifer (Chabart 1996). Historically, a numerical hydrodynamic model of the Roussillon basin was already elaborated (Auroux 1992), but no information were available about salt water intrusion risk and all of the deepest layers were simulated like a unique and homogeneous aquifer.

Moreover, knowledge of the lithology and geometry of the aquitards and aquicludes is as important as the ones of the aquifers particularly for interactions between aquifers on top of the other, for up-coning risk assessment, salt water encroachment dynamics through surfaces water bodies (rivers, lagoons,...) or directly through the sea, etc. For each aquifer, hydraulic head and density distribution constitute main parameters for characterising groundwater 3D flow.

Because water flow does not always follow sedimentologic boundaries, bringing together sedimentary units and hydrogeology is a necessary step. Transformation from geological model to hydrogeological model is based on chemical analysis, on pressure head observation and on field experience. In fact, from 41 geological units, less than 8 hydrogeological formations are kept for the step of modelling. This resolution cut is linked to many reasons: connexions existing between geological units underline by chemical analysis, lack of knowledge about hydrodynamic parameters, calculation limit for modelling and, the main one, majority of wells are fully screened thus, exploits several aquifers.

In the case of saltwater intrusion, the choice of hydrogeological model is important. For Roussillon basin case study, sharp interface model is not appropriate because the fifty-fifty concentration line is located close to seashore and, paradoxically, increase in salt content occurs five kilometres landward (from field electrical conductivity survey). Heterogeneity in geological formations and pumping variations contribute to the diffusion of salt in the contaminated area. So, the choice of using 3D variable-density flow and solute transport simulations allows determining vulnerable areas (freshwater becomes non-potable as soon as it mixes with seawater with the sea water exceeding 3%).

With the aim of clarifying, the Fig. 3 represents a conceptual hydrogeological model and its evolution through the groundwater development. Only three kinds of aquifers are presented, because the sketch focused on the coastal area.

Quaternary aquifers are mainly composed of alluviums (conglomerate, flood plain) and coastal deposits. The unconfined Quaternary aquifer lies along the main rivers and the coastline. It is mainly exploited by farmers, private and camping owners. Quaternary aquifer also supplies drinking water of Perpignan town. Water quality of the Quaternary upper aquifer is poor near the coast due to a high chloride concentration (e.g.: electrical conductivity can reach 5000 μS/cm at St-Laurent-de-la-Salanque - 5 km from the coastline).

The *Pliocene aquifers* (continental and marine), whose characteristics are linked to the Messinian event are built of fluvial deposits and marine sands and clays. Many wells in these aquifers were artesian thirty years ago. Now, artesian flowing wells are more and more uncommon. The confined Pliocene aquifers are mainly exploited for drinking-water supply and by farmers. Generally, both water quality and hydraulic head of the Pliocene aquifer increase with the depth of the exploiting well. Even under the beach barrier sand, water conserves a good quality:

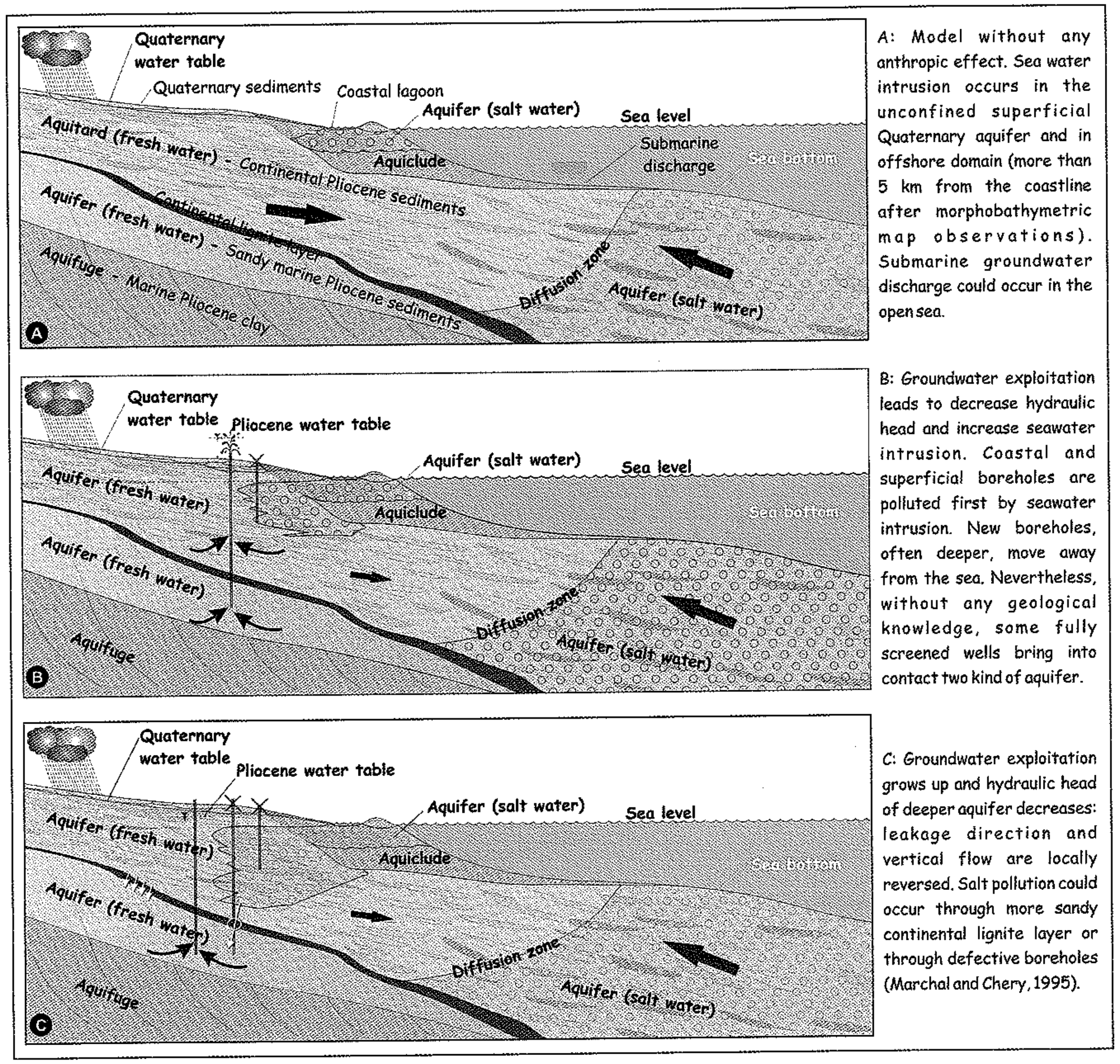

Fig. 3 – Hydrogeological conceptual model of Roussillon aquifer system without scale and location. This sketch presents historic groundwater development. The superficial layer has sea connections, meaning that overexploitation can generate sea water intrusion.

chloride concentrations are lower than 40 mg/l. Locally, some interconnections exist between the Quaternary and Pliocene aquifers, mainly because of two reasons: (i) leakage from pre-existing wells, (ii) incision of shift Pliocene aquifer by Quaternary channels. These interconnections tend towards decreasing Pliocene aquifer water quality.

Fluvial sands fill distributaries channels of deltaic complex constitute the *Continental Pliocene aquifer*. This aquifer contains excessive water mineralization only in the northern part of the basin, along the lagoon and even more so along the coast at Le Barcarès. The continental Pliocene aquifer is very productive, especially in the Salanque plain. Because of its geological setup (stream channel and flood plain alternations), this aquifer is considered like a heterogeneous aquifer: permeability tensor and salt water interface position could extremely vary in the three dimensions.

Usually, lignite layers alternating with marsh plastic clays are located beneath the Continental Pliocene aquifer. This non-continuous impervious layer separates continental Pliocene aquifer from sandy marine Pliocene aquifer.

Sandy marine Pliocene sediments correspond to the prograding deltaic shore face. Theoretically, this homogeneous aquifer is not connected to the sea and it is preserved from seawater intrusion. However, some area contains excessive mineralization. The origin of the contamination is the vertical leakage from the partially contaminated Quaternary aquifers to the Pliocene aquifers due to

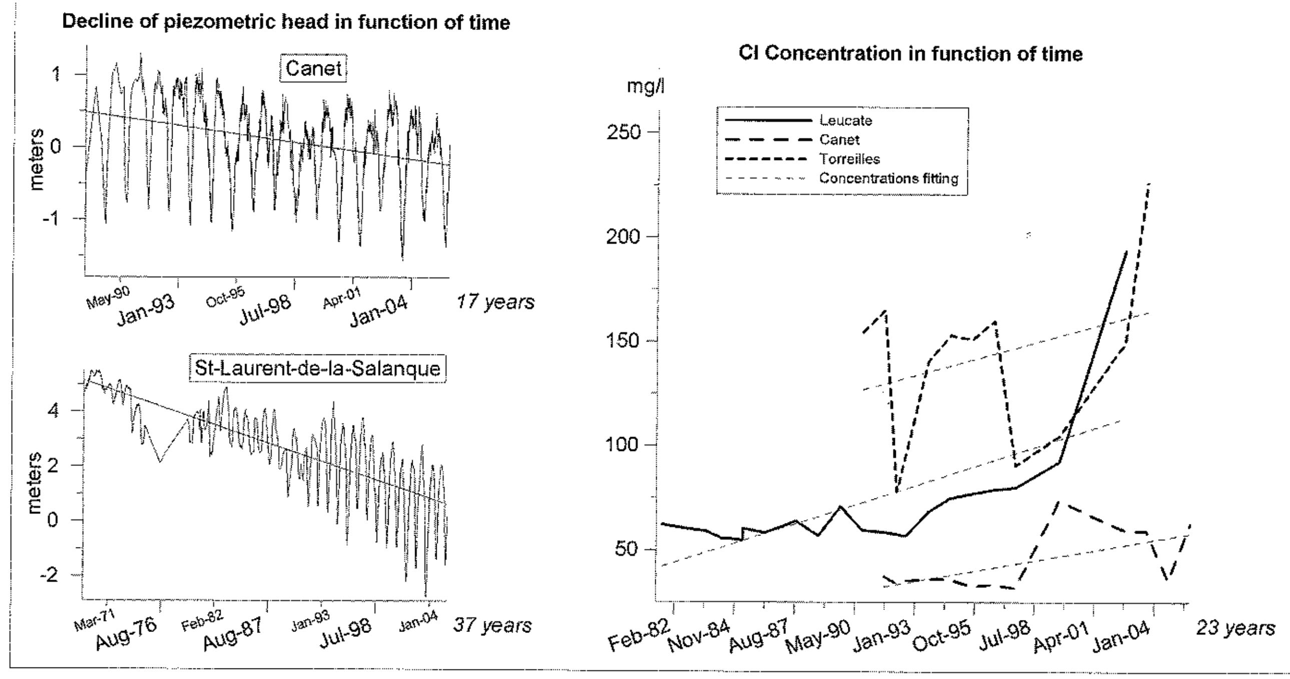

Fig. 4 – Piezometric head and chloride concentration both in function of time. All these observation points are located in the Pliocene aquifers close to the sea. Near the coast and since the beginning of exploitation, Pliocene aquifer water level have reached 0 meter more and more often during the year.

existence of defective boreholes (Fig. 4). New boreholes drilled next to the old ones show a strong decrease in the waters salt content. Without any water pumping, hydraulic head of the sandy marine Pliocene aquifer is higher than the continental Pliocene aquifers.

Sedimentary model provides geometry of aquifers and aquicludes for the modelling, while economic study suggests some management scenarios inspired by socio-economic context of the Roussillon basin.

MANAGING ROUSSILLON'S GROUNDWATER DEMAND: WHICH INSTRUMENTS TO IMPLEMENT?

Management of aquifer system exploitation requires detailed knowledge of demand and resource characteristics. On one hand, the demand information (type of use, extracted volume, demand price elasticity, the touched layer, etc.) allows establishing the socio-economic context. This, when combined with the resource characteristics, determines vulnerable zones (environmentally and/or economically) where policy instruments would prevent catastrophic consequences of overexploitation. On the other hand, given a particular socio-economic context, this information enables determining ex-ante efficiency of a policy instruments. However, a question remains open: which instrument among the plethora of management instruments to implement?

Usually in coastal areas, policies concerning the increase of water supply (dams, desalinization of seawater, aqueducts, etc.) have been already implemented, however, they might not be economically feasible (Groom *et al.* 2003, Giordana & Montginoul 2006). Then, demand reallocation policies emerge as the unique option. Many management solutions to control individual withdrawals like ranging from taxes (Baumol & Oates 1988), incentive mechanisms or regulations (Dasgupta *et al.* 1980) and facilities for self-organization (Ostrom 1990), have been suggested in the economic literature. To test these management solutions, the experimental economy method offers a workbench for different policy devices that would be implemented for real (Bohm 2003, Cummings 2001), avoiding some of the acceptability problems that a field test would imply as was observed in the Roussillon case.

The need for a smart integrated management of the water resource in the Roussillon plain has been early identified; self designed accords were passed between users (city governments and agricultural profession) and the water agency in order to preserve groundwater for human consumption. Then, between 1968 and 1995, three river dams and modern irrigation channels (pressure water network) were constructed to satisfy agricultural water demand (Connaissance des eaux souterraines de la plaine du Roussillon 2003). However, groundwater resources have allowed the development of modern irrigated agriculture outside the irrigation areas; they have also led to increasing non-potable water needs (swimming-pools, garden irrigation, etc.). Actually, the water authority has only partial information about the precise location of extraction points, the quality of the drills, and the quantity of water being extracted. In order to record every extraction point and recover the payment charges stated in the 1992's Water Law, the Water Agency has implemented different policies in the last decade (i.e. subventions to the installation of volume meters). Nevertheless, these policies have not completely solved the problem. Then, the experimental method would be very useful in designing new policies or modifying to the existing ones.

Experimental economy

An experiment in economy consists of an artificial reconstitution of an economic situation in a laboratory, offering comparative advantages of control and measurement with respect to naturally occurring settings (Ostrom *et al.* 1994, Roth 1995). By implementing a particular protocol, the experimentalist can carefully create conditions in a laboratory that closely match those specified in a theoretical model aimed to explain real occurring phenomena. In those cases, the experimental method can be highly useful to the design of empirical institutions and policies (Ostrom *et al.* 1994, Shogren 2005).

An important aspect in the reliability assessment of laboratory experimentation as a test-bench of public policy measures is the subject pool. Participants to experiment are in general undergraduate students; a common criticism is then, that a student pool is not representative of "real" people behaviour. Nevertheless, when the protocol is sufficiently abstract, a student pool fairly represents behaviour of a larger population (Lichtenstein & Slovic 1973). A problem emerges when context affects behaviour; in those cases some kind of field experimentation is unavoidable (Harrison & List 2004).

Our experimental research program aims to assess the efficiency of various institution policies to manage groundwater extractions. Still far away from a decision-making end-user, we have developed an experimental protocol based on an heuristic model that represents quite well the choice to which agents are confronted in the field.

Experimental test of a tax system with random audit

Protocol and simplifications

As stated in the previous sections, groundwater in the Roussillon plain occurs in a complex multilayered coastal aquifer. The Quaternary and Pliocene aquifers represent imperfect substitute water resources for end-users (as each layer presents freshwater of different quality and productivity). Then, from a behaviour point of view, the exploitation of a multilayered aquifer breaks results in two decisions: choice of the layer (choice between substitute resources) and the extracted quantity. Details on the experimental protocol implemented to study the exploitation of substitute groundwater resources can be found in Giordana *et al.* (2006). However, depending on the location in the plain, different water resources can be acceded (surface water, Quaternary or Pliocene aquifer).

To illustrate how experiments can be used to assess the efficiency of groundwater demand management instruments, we briefly present the observations of two of the implemented treatments. Here we consider a protocol in which only one groundwater resource is available. This means that we care about a zone of the Roussillon plain where there is just one layer (i.e. the Pliocene aquifer in the south-west of the plain), with existing boreholes; there is no possibility to drill new boreholes at least in the short term. Implementation in the laboratory requires a simple model of the resource dynamics as it must be explained to participants (a good comprehension of the task in the lab reduces noise in the observations). Then, we have omitted some hydrogeological details that would be confusing for participants: (i) no 3D variable density flow model is considered; (ii) in the economic model, groundwater is represented by a 2D "bathtub aquifer" (infinite hydraulic conductivity); actual withdrawals automatically produce a homogenous reduction of the hydraulic head (no up-conning risk) on the whole aquifer. In particular, salt water encroachment dynamics are modelled in the simplest possible way: as the available stock (hydraulic head) diminishes with extractions the water quality deteriorates homogeneously over the whole aquifer. More details on the experimental protocol (the model, participants' selection, rewards, data treatments, etc.) can be found in Giordana & Willinger (2006).

Experimental observations

We first evaluate a baseline treatment where participants, during a ten period dynamic game, were asked to extract in each period the quantity of water they want from a stock. In Fig. 5 the dashed line shows the mean extracted quantities in each period for the baseline treatment. Provided that the profit of groundwater exploitation

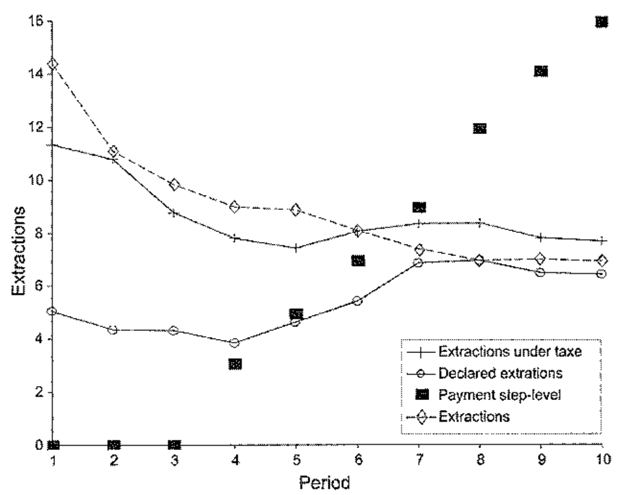

Fig. 5 – Mean extractions and declared extractions.

depends on the groundwater quality, as long as the stock decreases (as a result of excessive pumping), extractions also diminish because they are less profitable. Mean extractions are far to be optimal (the optimal extraction trajectory is indicated by the full square markers in Fig. 5); then, we say that the groundwater stock is overexploited.

We are aware about the efficiency of the tax system in encouraging a more sustainable use of groundwater. Thus, we test in the laboratory an incitation mechanism that consists of a unitary tax, applicable on the declared quantities. The tax would be paid only if the declared quantities exceed a step-level defined for each period (the full square marker in Fig. 5). In order to assure compliance, there is a fixed probability of audit. If declared quantities are controlled and came out to be less than those really extracted, a penalty is imposed. In the treatment exposed in figure 5, the penalty is very high. Nevertheless, the compliance rate (the ratio between the declared and the extracted quantities) remains quite low all along the time horizon (the circle marked full line lies under the diamond marked one). As a consequence, the extracted quantities have not been significantly reduced with the imposition of this tax system.

Questions as, how this incitation mechanism can be improved or whether a higher probability of audit raises the compliance rate or would another instrument out perform this mechanism, can be answered by the implementation of additional treatments in the laboratory. Finally, the coherence of the results can be assessed by an ex-post statistical analysis of data, and scenarios can be constructed on this basis.

SYNTHESIS

Pluridisciplinary approach of management of coastal aquifer is summarised by Fig. 6.

In the Roussillon basin, different geological methods applied on pre-existent data (BRGM's public underground database, logs from drinking water borehole, offshore seismic petroleum profiles,...) are used to determine spatial distribution of the sedimentary units, and particularly those that could be potential aquifers. Sedimentary units' characteristics like interconnections, granulometry and homogeneity are implemented in a hydrogeological study.

Coastal groundwater resources are frequently complex multi-layer aquifers, where the sensitivity of each layer to saltwater intrusion greatly depends on its geological characteristics and geometries (continuity between inland and offshore). Understanding this sensitivity is a prerequisite

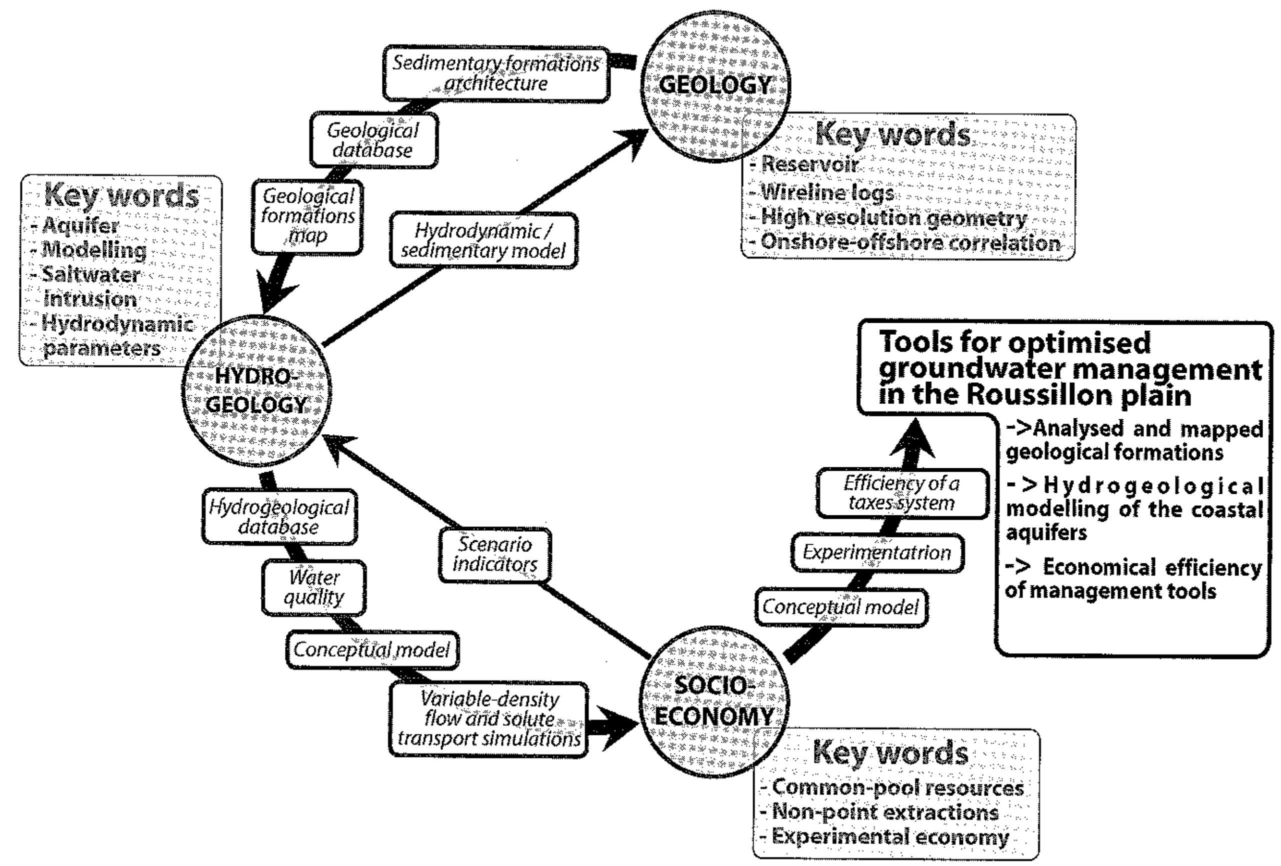

Fig. 6 – Synthetic sketch of the integrated methodology. Each step is dependent on the previous, but the study is led in parallel. Feedback between the three research fields also gives originality of the integrated methodology.

to design effective water management plans which would reduce abstraction in target aquifer layers. Built on a good sedimentary model, hydrogeological knowledge must be supplemented by long-time series observation (hydraulic head, hydraulic conductivity) and possibly hydrochemistry. However, numerous field measurements would be unused while screen locations in boreholes are unknown. So, the best way to understand how coastal aquifers work, is to observe and to be aware of what is observed. It's only later that modelling can answer water management issues. For reality sake, scenarios building must take into account the socio-economical framework of the studied area. So, experimental economy methodology offers a reliable way for ex-ante assessment of water management instruments. Predictions of the model resulting from coupling the economic dimension with the aquifer model could be tested and the efficiency of instruments assessed. However, in this paper the methodology is only illustrated with an example based on a heuristic economic model of groundwater extraction behaviour dynamics.

One of the aims of this paper is to demonstrate the importance of building studies based on relevant methodology that integrate most of groundwater resource problems encountered in coastal areas. For future prospects, methodology used in the case of the representative Roussillon basin could also be applicable to a certain extent to other coastal sedimentary basin.

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